RENEWABLE ENERGIES, ENVIRONMENT AND GDP INTERACTIONS IN LOW-INCOME COUNTRIES

Hafid Boudiaf
Faculty of Economic Sciences, University of Algiers 3 (Algeria)
E-mail: boudiafhh@gmail.com

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ABSTRACT

To determine the role of renewable energies in preserving the environment, and promoting economic growth in low-income countries, the study sampled 38 African countries, most of which belong to low-middle or low-income countries, according to the classification of the World Bank. The panel ARDL approach was used on time series covering the period 1990-2019. The most important results reached were the existence of a long-term cointegration relationship between the variables, a positive contribution of renewable energies to preserving the environment, through the negative impact on CO2 emissions, in contrast to economic growth, which had a positive effect on increasing CO2. On the other hand, there was no impact of renewable energies on GDP, the reason is that these renewable energies are traditional, and used directly from their natural sources, they cannot be used in the running economic cycle, and therefore have no effect on economic growth.

Keywords: African countries, ARDL, CO2 emissions, economic growth, renewable energies.
JEL Classification: C22, O55, Q43.

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INTERACCIONES DE ENERGÍAS RENOVABLES, MEDIO AMBIENTE
Y PIB EN PAÍSES DE INGRESOS BAJOS

RESUMEN

Para determinar el papel de las energías renovables en la preservación del medio ambiente y la promoción del crecimiento económico en los países de bajos ingresos, este estudio tomó una muestra de 38 países africanos, la mayoría de los cuales pertenecen a países de ingresos medios-bajos o bajos, según la clasificación del Banco Mundial. Se utilizó el método ARDL de panel en series temporales para el periodo 1990-2019. Los resultados más importantes muestran la existencia de una relación de cointegración de largo plazo entre las variables y una contribución positiva de las energías renovables en la preservación del medio ambiente, a través del impacto negativo en las emisiones de CO2, en contraste con el crecimiento económico que tuvo un impacto positivo en el aumento de CO2. Por otro lado, no hubo ningún efecto de las energías renovables en el PIB, la razón es que éstas se utilizan directamente de sus fuentes naturales por lo que no pueden usarse en el ciclo económico en curso y, por tanto, no tienen ningún efecto sobre el crecimiento económico.

Palabras clave: países africanos, ARDL, emisiones de CO2, crecimiento económico, energías renovables.
Clasificación JEL: C22, O55, Q43.

1. INTRODUCTION

With the advent of the Industrial Revolution in the eighteenth century, the consumption of fossil fuels doubled in various economic activities, as the source of energy needed to operate factories, move transportation and distribution equipment, in addition to other household uses, as well as the needs of the military machine, especially in the two world wars. Hydrocarbons, including coal, petroleum, and their derivatives, were economically exploited overly, with the aim of increasing production without taking due care of the environmental aspects.

The growing consumption of unclean energies has caused severe harm to all environmental aspects, terrestrial, sea and air, by exposing them to pollution from toxic gas emissions, including carbon dioxide (CO_2). In recent decades, and after the apparent emergence of the relative inability of nature to self-restore the environmental balance, and life of all kinds, human, animal, and plant, was affected, and climatic conditions deteriorated due to global warming, the international community with its various components, including international and regional bodies, and governments, moved at least in two directions. The first is spreading awareness of the necessity of preserving the environment and reducing the causes of pollution, and the second is researching solutions and implementing them in a way that activates the principle of prevention in conjunction with remedial measures (Kyoto Protocol, 2005; Paris Agreement, 2015).

The output-fossil energy conjunction constituted a chronic problem because output needs more consumption of very large quantities of fossil energy in order to meet the various commodity and service needs of about 8 billion people in the world, especially since traditional energy costs are low. This conjunction necessitated the continuity of CO_2 emissions in ascending order.

The amount of CO_2 emissions reached 34.34 million kt in 2019 globally (World Bank, 2023). It has caused an increase in environmental degradation, which will affect production factors negatively, including the land, where it is exposed to pollution and becomes unsuitable for cultivation and exploitation, as well as the labor factor, by affecting human health and safety, as this negatively affects the marginal productivity of labor, and capital factor is also negatively affected as part of the money is directed to treat pollution residues and disasters caused on global warming and climate change, rather than leading it to investment.

Among the available solutions is to move towards clean renewable energies in its various sources, as it is the alternative that carries the direct solution. Still, we need to overcome two obstacles: The high costs, and the relatively inadequate technology so far in providing the necessary commercial quantities, compared to what is provided by unclean energies.

Despite these obstacles, there is noticeable progress in implementing international agreements related to reducing CO_2 emissions, especially from some developed and high-income countries through the production and consumption of renewable energies. For example, Canada's consumption of renewable energies reached 22.11% of the total energy consumed in 2019, China 14.45%, France 15.53%, Germany 17.17%, Japan 7.69%, Italy 17.27%, the United Kingdom 12.24%, and the United States 10.42% (World Bank, 2023).

Low-income countries, including African ones, are considered countries that consume renewable energies in origin (except for countries that produce traditional energies), as they are not industrialized. Their developmental backwardness did not allow them to prepare their countries to use fossil energies in the same way that developed countries use, and they cannot even obtain traditional energies, because their prices are too high for them.

The consumption of renewable energies in low-income African countries is done directly from nature, without the need for complex technology to convert them into energies ready for modern uses, as is the case for developed countries. For example, Burundi's consumption of renewable energies equals 84.77% of the total energies consumed in 2019, Cameroon 79.41%, Central Africa 91.26%, Chad 77.79%, Congo, Democratic Republic 96.24%, Gabon 88.89% (World Bank, 2023).

These countries, if compared to the industrialized countries, we find that they are much less consuming fossil energy, and therefore less causing the emission of CO2 gas (IEA, 2022) because most of them are agricultural countries rather than industrial ones. Their low income makes their park of machinery, equipment, and transport vehicles consuming fossil energies, very narrow relative to industrialized countries one. Their Gross Domestic Product (GDP) depends mainly on rents or primary resources instead of manufacturing. For example, the amount of CO2 emissions in Burundi equals 720 kt in 2019, Central Africa 240 kt, Gabon 5,250 kt, compared to industrialized countries, Germany 657,400 kt, China 10.7 million kt, and the United States 4.8 million kt (World Bank, 2023).

Based on these facts, our research questions the impact of renewable energies on economic growth in low-income African countries from two angles: The angle of indirect effects on output through the impact on the environment by reducing CO2 emissions, and the angle of direct effect on output by including renewable energies as a determinant of growth.

This paper is organized as follows: Section 2 reviews the literature. Section 3 includes methodology. Section 4 presents the empirical results and discussion, and the final section concludes the paper.

2. LITERATURE REVIEW

The international community's increasing concerns about the environmental situation and climate change have resulted in decisive decisions regarding the reduction of CO2 emissions and gradually replacing of clean, renewable energy for unclean fossil energies. Researchers and academics moved in parallel and elaborated on the relationship between the two types of energy and their impact on both economic growth and CO2 emissions (Sosa and Vargas, 2022; Kolosok *et al.,* 2021; Acheampong and Opoku, 2023; Qudrat-Ullah and Nevo, 2021; Abdul-Mumuni, Mensah, and Fosu, 2023; Gwani and Sek, 2023; Seminario-Córdova, 2023). They used several analytical and measurement methods in different temporal and spatial areas of the world, to control the energy transition requirements at the lowest possible costs.

The energy was included in the growth models within the physical capital, just as human capital was included in the labor component, until endogenous growth theories appeared and included it as an independent component in the production function. Energy analysis in growth models as an independent component was, for several reasons, including:

1. Energy is one of the most important factors of production (Stern, 1997), the energy crises that occurred since the seventies of the last century showed the neglected importance of energy as a fundamental driver of the global economy, and the occurrence of an energy crisis leads to direct damage to economic and social conditions.
2. The increasing environmental deterioration resulting from the consumption of traditional energy necessitated identifying the negative impact of energy in order to manage it.
3. Transition to renewable energies also requires measuring their impact on economic growth, especially since their production is expensive and requires advanced technology compared to traditional energy.

Kraft and Kraft (1978) found that causality goes one way from gross national income (GNI) toward energy consumption in the United States in the period 1947-1974, and that energy does not cause GNI, *i.e.*, energy conservation policy does not affect economic growth. The study of Akarca and Long (1980), which implicitly tried to verify the results of Kraft and Kraft (1978), on the data of the same country and in approximately the same period 1947-1972, failed to prove any causal relationship between output and energy consumption. These results were confirmed by the study of Yu and Jin (1992), which maintained the spatial domain but changed the temporal domain to include the period 1974-1990 on monthly data.

Contrary to these results, there are studies whose results have proven a positive effect of energy consumption on economic growth. For example, the study of Streimikiene and Kasperowicz (2016) of the relationship between economic growth and energy consumption in 18 European Union countries showed the existence of cointegration between energy consumption and economic growth in the long run, and the relationship between them is positive. Stern and Cleveland (2004) confirmed a long-run cointegration relationship between GDP and energy consumption, which also found that energy use Granger causes GDP. They also reviewed the idea of the decrease in energy intensity per unit of economic output over time and found that the reason is primarily due to the shift from low-quality fuels such as coal to high-quality ones, especially electricity. They ruled out the possibility of significant decreases in energy intensity from its current level.

With regard to African countries, Wolde-Rufael (2005) found mixed results in his research on the relationship between energy consumption and economic growth in 19 African countries, as his study proved the existence of cointegration between the two variables in the long run for only eight countries. And causation is proven for 10 out of 19 countries. The different effects of energy on economic growth in various African countries were also confirmed by the study of Saidi, El Montasser, and Ajmi (2018), in the form of the relationship between per capita GDP and per capita energy consumption. Data included 12 African countries between 1978-2008, the results showed a significant negative impact of energy consumption on growth in some countries, while growth is positively affected by conservation energy in other countries.

Adams, Klobodu, and Opokub (2016) demonstrated the existence of a positive effect of energy consumption on economic growth in the long run. Their data cover the period 1971-2013 in 16 sub-Saharan African countries. The variables interact with a causal relationship in both directions. Similar results were obtained by Eggoh, Bangake, and

Rault (2011). In their study of the data of 21 African countries in the period 1970-2006, they divided the countries into two groups according to the criterion of net exporter/net importer of energy. This criterion did not make a significant difference, as the results demonstrated the positive impact of energy consumption on economic growth in the two groups.

Studies and research have recently expanded on the relationship between the triple economic growth —CO2 emissions— renewable energies. The analysis of Acaravci and Ozturk (2010) included 19 European countries; they use the Autoregressive Distributed Lag Model (ARDL) bounds test methodology. Their results proved that there is a long-term causal relationship between energy consumption, CO2 emissions, and economic growth in only seven countries. In contrast, the rest of the countries did not prove the causal relationship between the variables.

İnal *et al.* (2022) were interested in studying the oil-producing African countries as they are the most consuming fossil energy countries in the region; they consider the relationship renewable energies —CO2 emissions— growth during the years 1990-2014. The hypothesis of the impact of renewable energies on development in these countries was not achieved according to the results which also showed that increased growth leads to an increase in CO2 emissions. The same positive relationship between increased growth and CO2 emission was found by Azam *et al.* (2016) in their quest to determine the impact of CO2 emissions on environmental degradation in countries with a large rate of energy consumption and CO2 emissions, namely China, Japan and the United States.

York and McGee (2017) analyze the ability of renewable energies to decouple economic growth and CO2 emissions, their study covered the period 1960-2012. The results showed an interaction effect between the number of renewable energy sources and per capita GDP, and that the correlation of economic growth-emissions is greater in countries that produce a large share of electricity from renewable sources. The growth of renewable electricity negatively affects emissions to a lesser extent in richer countries. The authors justified these results by saying that increasing reliance on renewable energies was at the expense of reducing nuclear energy in rich countries, thus unintentionally relying on fossil fuels continues.

This paper includes original research that contributes to the efforts focused on studying the subject of environmental economics, which is one of the most important topics that preoccupy the international community with all its components, especially at the political and academic levels. This study is unique in identifying the various interactions between renewable energies, economic growth and the environment in terms of the impact, its value and direction, using appropriate standard tools for the case of low-income African countries, in an attempt to shed more light on decision-making in these countries and others, on the utmost necessity of serious work to reduce climate change and preserve the safety of the environment.

3. METHODOLOGY

3.1. Data

Our study seeks to show the impact of renewable energies consumption on economic growth in countries belonging to low-income categories. Our sample was limited to the African region. The sample selection was based on the availability of the necessary data for the study. The World Bank classification of countries was adopted based on income, as most African countries are classified into low-income categories.

The sample contains a total of 38 countries, 15 of which are classified as lower income, 19 lower-middle income, and only 4 are upper-middle income. While there is no country classified as high-income, the only African country classified in this category is the Seychelles, which is not present in our sample. Classification details are in Table 1.

3.2. Empirical methods

To extract the empirical results, the panel ARDL proposed by Pesaran and Shin (1998) and Pesaran, Shin, and Smith (2001) was used. This model is characterized by giving the results of the effects of the independent variables on the dependent variable in the short and long run. It is suitable for cases where time series are short, and data are limited. Different variables can also be included in terms of the stationary level in the model, whether they are integrated of order zero I(0), integrated of

Table 1. Classification of sample countries according to income level

Low income		Lower middle income		Upper middle income
Burkina Faso	Rwanda	Algeria	Kenya	Botswana
Burundi	Sierra Leone	Angola	Lesotho	Gabon
Congo, Democratic Republic	Sudan	Benin	Mauritania	Namibia
Gambia	Togo	Cameroon	Morocco	South Africa
Guinea	Uganda	Comoros	Nigeria	
Guinea-Bissau		Congo, Republic	Senegal	
Madagascar		Egypt	Tanzania	
Mali		Eswatini	Tunisia	
Mozambique		Ghana	Zimbabwe	
Niger		Ivory Coast		

Notes: All data are taken from the World Bank's WDI database, except energy consumption, which was taken from Our World in Data site web (2023), as follows: GDP, Gross Domestic Product (constant 2015 US$); CO2E, dioxide carbon emissions (kilotons); RE, renewable energy consumption (% of total final energy consumption); EC, energy consumption (TWh); KLR, capital labor ratio (the amount of capital per worker, constant 2015 US$).
Source: Prepared by the author based on the World Bank data.

order one I(1), or both. However, the inclusion of variables integrated of order two I(2) is not accepted.

After confirming the existence of a cointegration relationship between the variables of study, the long-run and short-run coefficients are estimated, including the error correction coefficient (ECT), which measures the speed of adjustment in the independent variables to return to the long-run equilibrium. Determining the lengths of lags depends on the Akaike Information Criterion (AIC). The estimated model is denoted as follows: ARDL (p, $q1$, $q2$, …), where p refers to the lag length of the dependent variable, and $q1$, $q2$ … denote the lag lengths of the independent variables.

The following equation gives the general form of the model:

$$Y_{it} = \sum_{j=1}^{p} \delta_{ij} Y_{i,t-j} + \sum_{j=0}^{q} \beta_{ij} \mathbf{X}_{i,t-j} + \mu_i + \varepsilon_{it} \qquad [1]$$

Where Y_{it}, is the dependent variable; $\mathbf{X}_{i,t-j}$, vector of the independent variables for group i; j, studied country; μ_i, country-specific fixed effect; p and q, lag lengths.

The first ARDL model in this study, which contains variables by logarithm, is represented in the following form:

$$\begin{aligned} LCO2E_{it} = {} & \phi_i \left(LCO2_{i,t-1} - \gamma_{1i} LEC_{i,t} - \gamma_{2i} LGDP_{i,t} - \gamma_{3i} LRE_{i,t} \right) \\ & + \sum_{j=1}^{p-1} \delta_{ij} \Delta CO2E_{i,t-j} + \sum_{j=0}^{q-1} \beta_{1i} \Delta LEC_{i,t-j} + \sum_{j=0}^{q-1} \beta_{2i} \Delta LGDP_{i,t-j} \qquad [2] \\ & + \sum_{j=0}^{q-1} \beta_{3i} \Delta LRE_{i,t-j} + \mu_i + \varepsilon_{it} \end{aligned}$$

Where $LCO2E$ is the logarithm of dioxide carbon emissions; LEC, logarithm of energy consumption; $LGDP$, logarithm of GDP; LRE, logarithm of renewable energy consumption; γ, long-run coefficients of the independent variable; δ and β, short-run coefficients; ε_{it}, error term; ϕ, speed of adjustment to the long-run equilibrium; i and t, country and period, respectively.

The second ARDL model in this study is represented as follows:

$$\begin{aligned} GDP_{it} = {} & \phi_i \left(GDP_{i,t-1} - \gamma_{1i} LEC_{i,t} - \gamma_{2i} KLR_{i,t} - \gamma_{3i} LRE_{i,t} \right) \\ & + \sum_{j=1}^{p-1} \delta_{ij} \Delta GDP_{i,t-j} + \sum_{j=0}^{q-1} \beta_{1i} \Delta LEC_{i,t-j} + \sum_{j=0}^{q-1} \beta_{2i} \Delta KLR_{i,t-j} \qquad [3] \\ & + \sum_{j=0}^{q-1} \beta_{3i} \Delta LRE_{i,t-j} + \mu_i + \varepsilon_{it} \end{aligned}$$

Where GDP is the independent variable, and KLR represents the capital-labor ratio.

4. RESULTS AND DISCUSSIONS

The study investigates the impact of renewable energies consumption on economic growth in middle-income and low-income African countries. It begins with the unit root test, followed by estimating the first ARDL model to consider the indirect impact of renewable energies on economic growth through its impact on CO2 emissions, and then the second model follows to determine the direct effect.

4.1. Unit root test

The five variables used in the study were subjected to four tests to detect the unit root. Two of them assume a common unit root process, which are the tests of Levin, Lin and Chu and Breitung. The other two assume individual unit root process, and are the Im, Pesaran and Shin and Augmented Dickey-Fuller (ADF) tests. Results are shown in Tables 2 and 3.

Table 2. Unit root test at level

Variables	Intercept and trend	Intercept	None
Levin, Lin, and Chu			
CO2E	1.45251	11.0100	17.7579
EC	0.55147	8.12081	12.4509
GDP	1.91852	21.3498	32.7527
RE	–0.31022	1.63380	–5.67359***
KLR	–1.76620**	5.86871	6.48022
Breitung t-statistics			
CO2E	7.65964	-	-
EC	8.05734	-	-
GDP	13.7005	-	-
RE	–0.52783	-	-
KLR	7.45813	-	-

Table 2. Unit root test at level (concluded)

Variables	Intercept and trend	Intercept	None
Im, Pesaran and Shin			
CO2E	2.63289	15.6660	-
EC	1.75672	12.6912	-
GDP	7.14225	23.4442	-
RE	0.34171	4.32247	-
KLR	–0.10711	8.37595	-
ADF-Fisher Chi-square			
CO2E	67.6321	17.9477	5.91276
EC	77.5230	18.4431	9.22668
GDP	51.8062	13.6463	1.92968
RE	76.6589	45.4845	157.318***
KLR	89.8131	29.3163	47.1495

Note: *** Significant at 1%, ** significant at 5%, *significant at 10%.
Source: Author compilation from E-Views outputs.

Table 3. Unit root test of the first differences

Variables	Intercept and trend	Intercept	None
Levin, Lin, and Chu			
CO2E	–22.5205***	–24.2188***	–17.2857***
EC	–20.5374***	–23.3422***	–18.4617***
GDP	–12.1707***	–8.13512***	–2.13789**
RE	–22.1977***	–25.1804***	–26.2841***
KLR	–20.5676***	–22.5467	–24.5497

Table 3. Unit root test of the first differences (concluded)

Variables	Intercept and trend	Intercept	None
Breitung t-statistics			
CO2E	–9.03312***	-	-
EC	–9.71222***	-	-
GDP	–1.66323**	-	-
RE	–17.2342***	-	-
KLR	–3.53492***	-	-
Im, Pesaran and Shin			
CO2E	–24.3501***	–23.4014***	-
EC	–21.2687***	–23.2623***	-
GDP	–13.1747***	–9.04354***	-
RE	–21.8456***	–24.2438***	-
KLR	–22.1378***	–22.5307	-
ADF-Fisher Chi-square			
CO2E	596.149***	601.423***	506.939***
EC	502.620***	601.015***	579.654***
GDP	331.202***	294.396***	226.881***
RE	503.130***	607.883***	730.201***
KLR	543.417***	573.671	741.783

Note: *** Significant at 1%, ** significant at 5%, *significant at 10%.
Source: Author compilation from E-Views outputs.

It is clear from Table 1 that all study variables are non-stationary at the level, which calls for re-testing the unit root at the first difference for all variables. The results are shown in Table 3.

Table 2 shows that the various unit root tests proved that all series are stationary at first differences; that is, they are integrated of the first order I(1). These results allow us to treat our problem econometrically using the ARDL model.

4.2. The impact of renewable energies on CO2 emissions

In the first stage, the first model was estimated to determine the impact of renewable energy consumption on CO2 emissions in the sample countries. The two variables of energy consumption and GDP were included as control variables. Among the estimated models, the ARDL (1,1,1,1) model was selected according to the AIC information criterion. Results are in Table 4.

The ECT is negative and statistically significant according to the t-statistics and p-value, which means the existence of cointegration between the variables of study in the long run. This coefficient contributes to correcting the relationship between variables in the short run to adjust and keep it balanced in the long term. The adjustment speed is relatively large, at 75.4% per annum; that is, the occurrence of a shock only needs about one year and four months to return to the state of equilibrium in the long run. It is the time sufficient for the independent variables to change until it fully affects the dependent variable.

Table 4. Estimation results

Variables	Δ*LCO2E*	Probability	Variables	Δ*LCO2E*	Probability
Long-Run			Short-Run		
Δ*LEC*	0.140911***	0.0000	Δ*LEC*	0.044243	0.3739
	(4.55)			(0.88)	
Δ*LGDP*	0.435708***	0.0000	Δ*LGDP*	0.171795	0.3100
	(6.34)			(1.01)	
Δ*LRE*	−0.479876***	0.0000	Δ*LRE*	−1.846021***	0.0004
	(−8.60)			(−3.56)	
ECT(−1)	−0.754696	0.0000	CONST	0.016500***	0.0030
	(−15.81)			(2.97)	

Notes: *** Significant at 1%, ** significant at 5%, *significant at 10%. Δ is the difference operator, t-statistics in parentheses.
Source: Author compilation from E-Views outputs.

In the long run, we note that all independent variables are statistically significant, according to the Student test as well as probability values. The parameter of energy consumption is positive, which corresponds to economic theory. Its value is equal to 0.14, meaning that a change in energy consumption by 1% leads to a change in carbon dioxide emissions by 0.14% in the same direction, and this means that energy consumption is an important determinant of carbon emissions in the long run in low-income African countries.

The GDP parameter is also positive and strong, with a value of 0.43. A 1% change in output leads to a 0.43% change in CO_2 emissions in the same direction, which matches reality and economic theory. The output increases with the increase in investments, which requires an increase in the consumption of operational energy and energy for logistical requirements, thus increasing CO_2 emissions due to energy combustion. On the other hand, an increase in real GDP means an increase in relative welfare, which leads to an expansion of the park of vehicles, devices, equipment, and machinery, which in turn needs fossil energy, and causes an increase in CO_2 emissions. We conclude that increasing GDP increases CO_2 emissions through two channels, the investment and consumption activities channels.

The renewable energies parameter expresses the inverse relationship between the consumption of clean, renewable energies and CO_2 emissions, with a value of –0.48. Its negative sign indicates the effect is in the opposite direction, consistent with economic theory. Increasing the consumption of renewable energies by 1% of the total energies consumed leads to a decrease in CO_2 emissions by 0.48%.

In the short run, we note that the parameters of energy consumption and GDP are not statistically significant, despite their economic acceptability. Therefore no effect on CO_2 emission can be proven in the short run through these results.

The parameter of consumption of renewable energies is statistically significant as shown by the t-statistic and p-value from Table 3, its negative sign expressing it is consistent with economic theory. An increase in the consumption of renewable energies by 1% of the total energies consumed leads to a decrease in CO_2 emission by 1.84%.

4.3. The impact of renewable energies on GDP

The estimation outputs resulted in selecting the optimal model according to AIC information criterion, which is ARDL (1,1,1,1), GDP is the independent variable. Energy consumption and capital-labor ratio are control variables. Details in Table 5.

From the above Table, it is clear that the ECT is negative and statistically acceptable at a significant level of 1%, indicating the existence of a long-term c-integration relationship between the variables of the study. Its value of –0.54 indicates that the rate of adjustment to return to equilibrium in the long run reaches 54% annually. About 22 months is sufficient for the interaction and adjustment of the independent variables for long-term rebalancing.

In the long run, we note that the energy consumption coefficient is statistically significant, while economically, it greatly affects GDP in sample countries. The value of the coefficient is large and is explained by an increase in GDP by about 41 million US dollars due to a rise in energy consumption by 1 TWh. The capital-labor ratio is also statistically

Table 5. Estimation results

Variables	ΔGDP	Probability	Variables	ΔGDP	Probability
Long-Run			Short-Run		
ΔEC	41,091,742	0.0001	ΔEC	–7,128,002	0.5357
	(3.86)			(–0.61)	
ΔKLR	301,313.9	0.0000	ΔKLR	1,857,489	0.0123
	(6.93)			(2.50)	
ΔRE	161,988.9	0.7382	ΔRE	82,893,931	0.1295
	(0.33)			(1.51)	
$ECT(-1)$	–0.542801	0.0000	CONST	5.37E+08	0.0003
	(–10.60)			(3.66)	

Notes: *** Significant at 1%, ** significant at 5%, *significant at 10%. Δ is the difference operator, t-statistics in parentheses.
Source: Author compilation from E-Views outputs.

significant at all levels and indicates that every $1 increase in KLR leads to an increase in GDP by about $301,314.

The renewable energies consumption coefficient is not statistically acceptable at all significant levels (t-statistics and p-value). According to these results, we could not prove the impact of renewable energy consumption on economic growth in the sample countries,

In the short run, we note that the coefficients of all independent variables are unacceptable at 10% level of significance or less, except for KLR, its coefficient is statistically significant at 5% level, where an increase in capital corresponding to one worker by $1 leads to an increase in the output of the sample countries by about $1.85 million.

By matching the applied results obtained in the two models with the main hypothesis of the research, we find that it is fulfilled in its part related to the contribution of economic growth to increasing CO2 emissions, due to excessive growth relying on fossil energies. In contrast, renewable energies contribute to reducing CO2 emissions. As for the part related to the impact of renewable energies on economic growth, the results did not match expectations, as the model failed to prove the assumed positive effect.

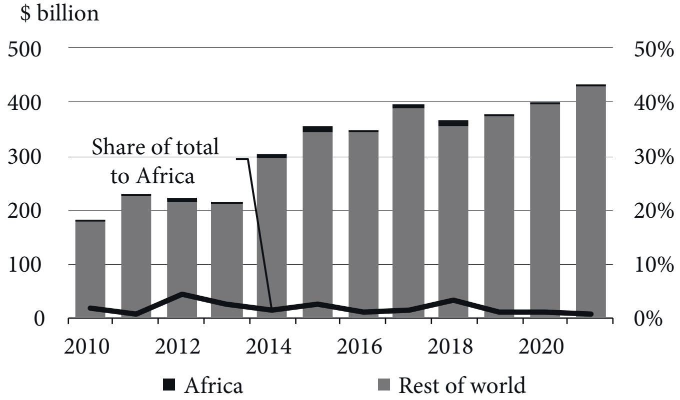
The results obtained from the first model indicate that the consumption of renewable energies contributes to reducing CO2 emissions in African countries, both in the short and long periods. Because increasing the percentage of renewable energies from the total energy mix has direct effects on reducing toxic emissions, especially in the case of replacing fossil energies with clean energies.

The case of African countries is unique, as they have very high rates of consumption of renewable energies compared to the rest of the world, but this scene falsifies the fact that these energies are used in a primitive way directly from nature, and most of their sources are biomass (JRC, 2011; IEA, 2022).

Africa is considered the weakest region in terms of investment in modern renewable energies. For example, its investment rate for the year 2021 was just 0.6% of the total investments in the world, or about $2.6 billion from $434 billion globally (Figure 1).

A distinction must be made between modern renewable energies (MRE), whose sources are used to generate clean energy, largely in economic and social uses in its developed form, and traditional renewable

Figure 1. Global renewable energy asset investment by region

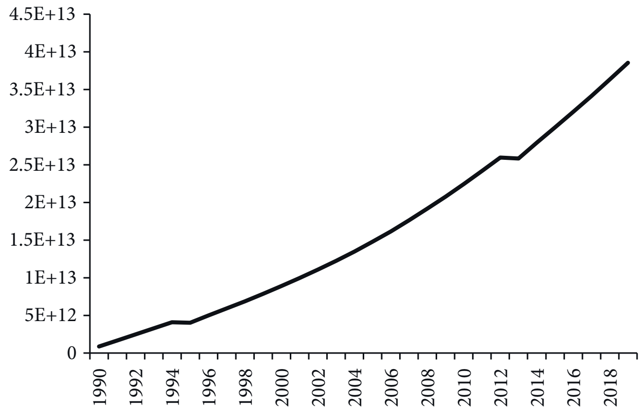


Source: BloombergNEF (2022, p. 2).

energy (TRE), which is confined to natural organic fuels such as wood, charcoal, agricultural waste, and animal waste, which African countries use more for domestic uses than for productivity purposes, by virtue of the non-industrial nature of African countries.

The second estimated model explains economic growth trends in low-income African countries, which indicate a steady increase in real gross direct product values over time (Figure 2).

Figure 2. Trends of real GDP in African low-income countries (2015 US$)



Source: Elaborated by the author based on WDI data.

The second estimated model showed that the consumption of renewable energies in African countries did not contribute to economic growth rates, neither in the short run nor in the long run, in contrast to the consumption of fossil energy and capital, which contributed to economic growth with significant values.

Fossil fuels are used directly in productive activities and social uses or through their use as inputs to generate electricity.

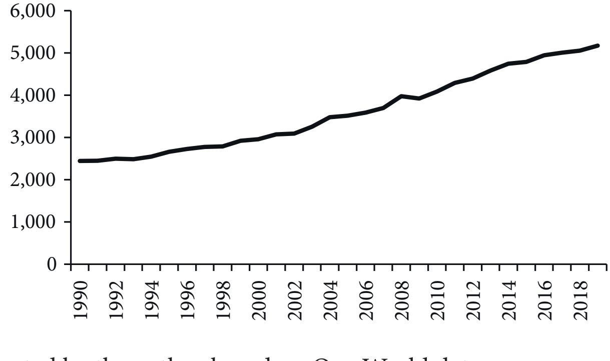
Their demand is increasing over time due to the increase in the population, which generates an increase in the demand for energy due to the production needs and for the necessity of domestic uses such as heating, cooling, and cooking, which explains the similarity of its trends with the trends of the gross domestic product, as illustrated in Figure 3.

But if we talk about modern renewable energies in African countries (with some exceptions, such as South Africa, Morocco, Egypt and Kenya), there is hardly anything to mention, compared to the rest of the world.

Looking at the energy sources consumed in African countries, we find that fossil energies dominate the energy mix, while modern renewable energy sources have a weak contribution and are characterized by concentration in some countries and not others, as well as mainly confined to hydro energy.

Suppose we monitor the generations of energy over time. In that case, we find that it passed through the first generation represented by traditional renewable energies. The second generation is represented by fossil energies such as coal, oil, gas, etc., and now, with technological

Figure 3. Trends of EC in African low-income countries, 1990-2019 (TWh)



Source: Elaborated by the author based on Our World data.

development, there are signs of a shift towards the third generation represented by modern renewable energies (see Figures 4 and 5).

Most African countries are still in the first generation phase due to the scarcity of fossil energies in them and the inability of these countries to purchase these energies due to their low incomes. Some of them moved to the second generation as producers of either coal or oil and gas, and others imported these energies, which explains the general trend of traditional renewable energy consumption, as it decreases over time in favor of fossil energies, as shown in Figure 6.

Figure 4. Annual power generation by technology in Africa

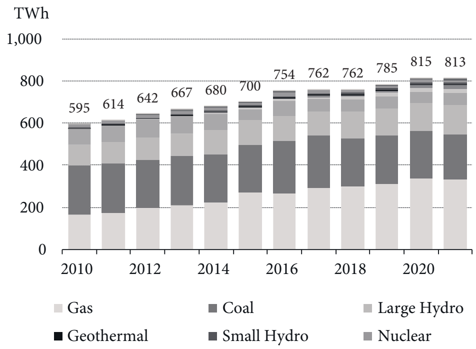
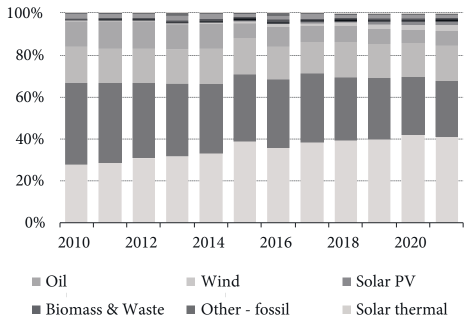
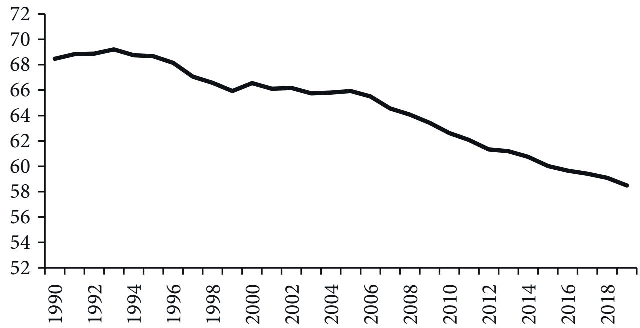


Figure 5. Share of annual power generation by technology in Africa



Source: BloombergNEF (2022, p. 9).

Figure 6. Trends of TRE as share from total energy in low-income African countries (%)



Source: Elaborated by the author based on WDI data.

Let's discuss the idea of African countries jumping from the first energy generation to the third without going through the second generation, especially since they contain extensive sources of renewable energies of all kinds, perhaps the most important of which is solar energy. This option seems currently excluded despite its many advantages for the region, and the reason remains the same, which is the weak income in the face of the characteristics of modern renewable energies that are high in cost because they depend on modern, complex, and high-cost technology, which makes it difficult to obtain and exploit.

There is a possible way out represented by moving towards foreign direct investments, and this depends above all on the availability of the political will to shift towards renewable energies in these countries, and secondly, the ability to attract specialized companies in this field, especially in terms of providing an incubating environment for these investments. Third, development of technology to the extent that it allows the provision of significant commercial quantities at reasonable costs.

By excluding this scenario, the option of switching to the second generation in the future remains almost inevitable, in light of the current prevailing conditions, because the transformation of industrial countries that consume fossil energies in very large proportions to clean energies, will reduce the demand for fossil energies to lower levels, resulting in a decrease in their prices to the extent to which low-income African countries can buy and use large quantities. Thus, developing countries replace developed countries in terms of demand for fossil energies. The realization of this scenario brings us back to talking about global efforts to reduce emissions that are harmful to the environment and cause global warming because this scenario indicates the continuation of the causes of CO2 emissions.

The solution to this problem remains based on possibilities, one of which may be the support of international donor bodies for the necessary infrastructure to attract foreign direct investment in this field, or perhaps a decrease in production costs due to an important technological development and this remains dependent on what happens in the future.

5. CONCLUSION

The study dealt with the impact of renewable energies on economic growth directly through its inclusion as a determinant of growth in the estimated model on the one hand, and on the other hand its indirect impact on growth, through its role in the effect on the environment. It included the case of African countries belonging to the low-income categories, as this region is characterized by the wide consumption of renewable energies, and its small contribution to CO2 emissions, because they are non-industrialized countries, whose incomes depend primarily on agriculture, primary resources, or rents.

The results of the applied studies on this subject varied according to the temporal and spatial domains, the different characteristics of the prevailing economic activities among the studied regions, as well as the different countries in terms of the abundance of fossil energies. Some researchers found a positive effect of renewable energies on economic growth, and a negative effect on CO2 emissions, while others found the opposite.

The results of our study revealed the existence of a long-term cointegration relationship between the variables of the study in the two estimated models, and the presence of a negative impact of the consumption of renewable energies on CO2 emissions in the sample countries in both the short and long run. The renewable energies used in these countries are traditional energies with direct uses from nature, which are unsuitable for modern domestic use or production and service uses. This explains the inability of renewable energies to contribute to GDP, according to the results of the second model, which includes renewable energies as a variable explaining growth.

The discussion of the results in the sample countries on the triple renewable energies —CO2 emissions— economic growth revealed that the current situation serves the environment at the expense of economic development. The use of traditional renewable energies contributes to reducing CO2 emissions, but the inability to use them in operating the production cycle makes them a growth inhibitor.

The second possible situation and candidate for application in the future is the shift of the sample countries to the use of fossil energies according to the following mechanism: The major industrial powers turn to the use of modern renewable energies and abandon fossil energies, which results in a significant decrease in the demand for fossil energies, and thus a decrease in their prices to the extent that makes the sample countries able to purchase and use fossil energies. This scenario depends on the extent of technological development in this field, so it can produce quantities of clean energy to compensate for fossil energies in developed countries. This situation serves economic growth at the expense of environmental pollution.

The third situation is to jump to the use of modern renewable energies (without going through fossil energies) given that their sources are well available in the countries of the region, and this is only possible through foreign direct investments due to financial and technological constraints, if appropriate conditions are available, such as political will, political stability, and the incubating infrastructure for this type of investment. This situation is ideal for serving the output and preserving the environment together. ◄

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